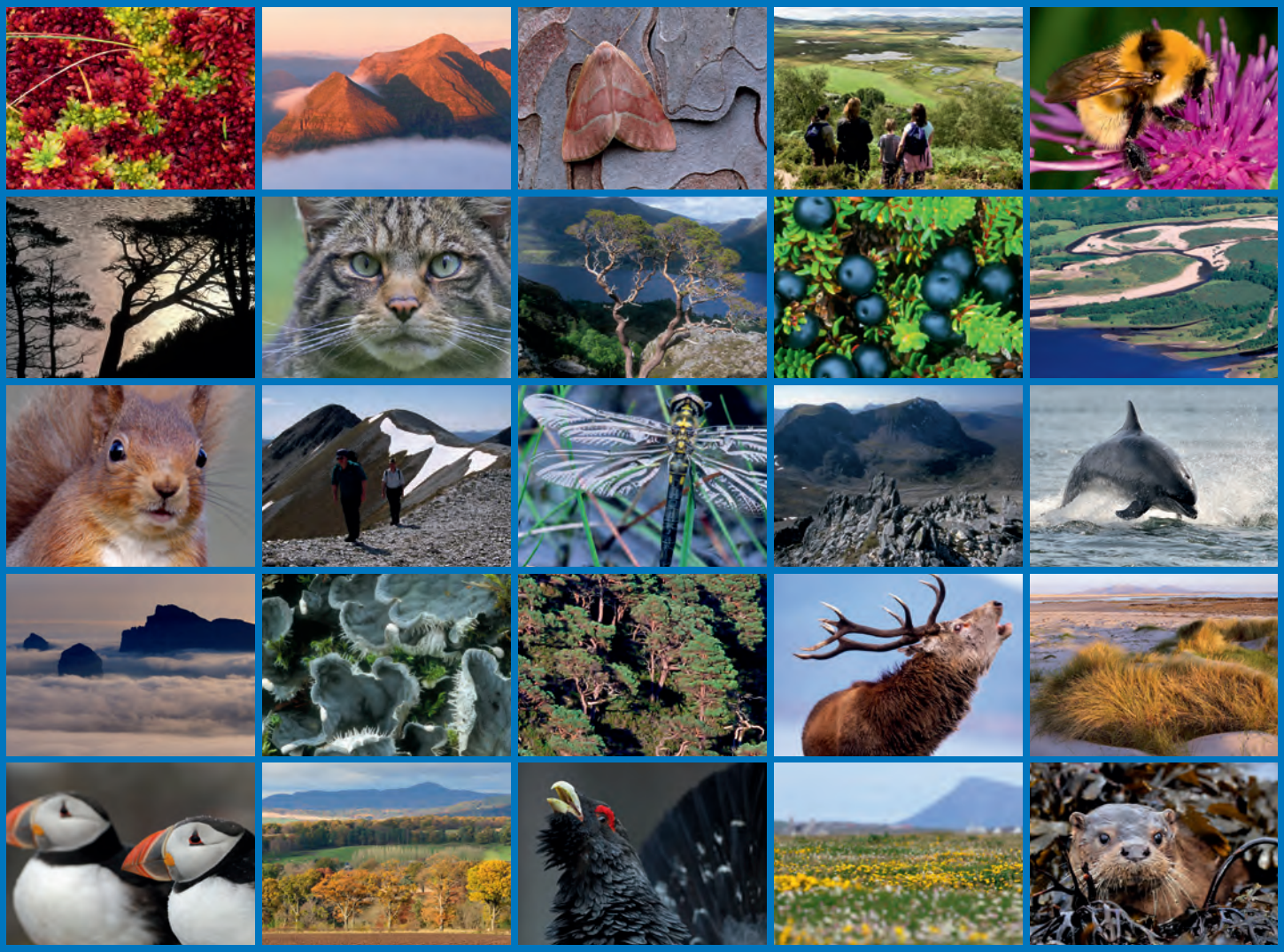
Scottish Natural Heritage
Commissioned Report No. 484

Control of New Zealand pygmyweed (*Crassula helmsii*) at Mochrum Lochs SSSI: phase II, 2008 – 2009



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COMMISSIONED REPORT

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Control of New Zealand pygmyweed (*Crassula helmsii*) at Mochrum Lochs SSSI: phase II, 2008 – 2009

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COMMISSIONED REPORT

Summary

Control of New Zealand pygmyweed (*Crassula helmsii*) at Mochrum Lochs SSSI: phase II, 2008 – 2009

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Background

New Zealand pygmyweed (*Crassula helmsii*) is an invasive, non-native, aquatic plant species, which tolerates a wide range of conditions of hydrology, substrate and water chemistry, and is able to regenerate from small fragments. These attributes have resulted in the rapid colonisation of habitats and dominance of *C. helmsii* over native species in standing water bodies throughout mainland Britain.

C. helmsii was recorded in Mochrum Loch in 2004. The Mochrum Lochs site is designated as an SAC due to its internationally important bog habitats. Mochrum Lochs SSSI is designated for features of interest which include oligotrophic lochs, blanket bog and breeding bird assemblages. The SSSI includes three water bodies: Castle Loch, Black Loch and Mochrum Loch, along with extensive areas of wetland. Presence of *C. helmsii* in Mochrum Loch means that this site is in unfavourable condition, so a programme of survey and management was instigated, aimed at eradication of the species from this site. The work is taking place within the Species Action Framework. In phase I, *C. helmsii* was found to occupy approximately 1 ha of the submerged and edge habitats of Mochrum Loch. Management strategies were considered and shading using weed control fabric (WCF) was selected as the initial method of treatment.

Main findings

- Significant control of *C. helmsii* appeared to have been achieved in the areas covered by WCF between March 2008, and December 2008 and March 2009.
- A total coverage of 359 m^2 of habitat by *C. helmsii* remained in March 2009, a 96% reduction from the level of infestation prior to the application of WCF.
- Herbicide was applied to residual *C. helmsii* plants in March 2009, but significantly less herbicide was required than would have been needed to treat the original level of infestation, had WCF not been used initially.
- Due to the invasive nature of the plant and its ability to spread from small fragments, it is anticipated that further measures will be required, to continue to control the growth and spread of *C. helmsii* within Mochrum Lochs SSSI.

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1. INTRODUCTION

New Zealand pygmyweed (*Crassula helmsii*) is an invasive, non-native plant, which grows in standing water, marginal and wetland habitats, where it is able to establish and spread rapidly. *C. helmsii* is a monoecious perennial (Preston and Croft, 1997), which regenerates from small fragments, and can rapidly colonise and dominate a plant community. Due to its highly competitive nature and ability to produce dense stands of vegetation, it is believed to be a significant threat to native species of aquatic and riparian vegetation, in the sites to which it is introduced (Kemp and Birkinshaw, 2005). A native of Australia, Tasmania and New Zealand, the species was first sold in Britain as a plant suitable for outdoor ponds in 1927 (Preston and Croft, 1997). The timing of its first release to the wild is unknown, but a naturalised population was recorded in 1956 (Laundon, 1961; in Preston and Croft, 1997). Available records suggest that the distribution of *C. helmsii* increased most rapidly in its distribution between 1980 and 1990 (Willby, 2008). However, although rate of spread appears to have decreased in recent years, C. *helmsii* has been recorded areas of conservation importance, such as Brown Moss, Swanholme Lakes and Hatchet Pond in England (Kemp and Birkinshaw, 2005). In Scotland, there are records for 53 populations, of which it is likely that 45-50 remain extant (Willby, 2008).

C. helmsii is present in Mochrum Lochs Special Area of Conservation (SAC), where it was first recorded during Site Condition Monitoring (SCM) in 2004. This site is situated in south-west Scotland (Figure 1, Appendix 1). It is designated an SAC due to the international importance of its blanket bogs and blanket bog depressions on peat substrates. Mochrum Lochs Site of Special Scientific Interest (SSSI) is of national importance for its standing waters and associated aquatic ecology. Breeding birds and blanket bog are also notified under the SSSI. The standing water feature of interest includes Mochrum Loch, Castle Loch and Black Loch (Figure 2, Appendix 1), as these standing waters were judged to be the best examples of lowland oligotrophic waters in the District.

Mochrum Loch supports macrophyte species typical of oligotrophic to mesotrophic lake types, including *Isoetes lacustris*, *Littorella uniflora* and *Lobelia dortmanna*. In addition to these three isoetid species, Black Loch also supports a fourth plant of this type, *Subularia aquatica*. However, a number of the macrophyte species observed in the Loch are more usually associated with eutrophic conditions, e.g. *Lemna minor* and *Potamogeton crispus*. Elevated levels of total phosphorus (TP) and algal blooms have been recorded in Mochrum Loch, indicating that nutrient enrichment is occurring within the water body. This may exacerbate the problem of growth of *C. helmsii* in the Loch, as invasive non-native plants may become a greater problem in enriched water bodies, if they have strategies for dealing with low or variable levels of CO_2 in the water column (e.g. the ability to use bicarbonate or respiratory CO_2), and/or are able to assimilate nutrients through the leaves. As *C. helmsii* tolerates a variety of conditions, from nutrient-poor and acidic, to eutrophic or calcareous (Preston and Croft, 1997), this suggests that *C. helmsii* may be adapted in such ways.

Due to the presence of *C. helmsii* in Mochrum Loch, the SSSI is in unfavourable condition. It is therefore necessary to attempt to eradicate the species from this site. As *C. helmsii* is a threat to biodiversity, it is included in the Species Action Framework (SAF) (http://www.snh.gov.uk/protecting-scotlands-nature/species-action-framework/).This initiative was developed to support delivery of the requirements of the Nature Conservation (Scotland) Act 2004 and the Scottish Biodiversity Strategy. Since the SAF promotes targeted management of *C. helmsii*, it was appropriate to undertake management of *C. helmsii* under the SAF programme.

Phase I of the project was undertaken in 2007/2008. Castle Loch and Black Loch were checked for the presence of *C. helmsii*, but it was not recorded. The distribution of the species in Mochrum Loch was investigated, as were the distribution and abundance of the

native macrophyte species. Methods for management of the *C. helmsii* were considered and shading using WCF was selected as the method of control which would be used in the first instance. WCF was installed and left in place for at least 6 months. On its removal, it was found that of the 10,000 m^2 of cover by *C. helmsii*, only 359 m^2 remained. Although this represented a 96% reduction in cover, there remained a population of plants from which *C. helmsii* could recolonise much of the available habitat of Mochrum Loch. The aim of this project remains the eradication of the species from this site. Further measures were therefore necessary.

The aims of phase II of the project were as follows:

- to determine the distribution and abundance of *C. helmsii* at Mochrum Loch
- to survey Castle Loch and Black Loch to search for *C. helmsii*
- to assess success of treatment of *C. helmsii* and regeneration of native species in the fixed transects
- to design and implement a plan for management of *C. helmsii* in phase II based on the results of survey
- to make recommendations for future management of *C. helmsii* at this site.

2. METHODOLOGY

2.1 Survey methods

Surveys were undertaken in phase 1 of this project (2007/2008), in order to provide information for the management plan, and to allow monitoring of the effects of management of *C. helmsii*. Surveys included the following:

- an initial survey of the aquatic vegetation of the Mochrum Lochs complex, including Mochrum Loch, Black Loch and Castle Loch, to give baseline data on the native aquatic plant communities and to map areas of *C. helmsii* infestation
- transect surveys of aquatic vegetation in Mochrum Loch, to form a baseline for future monitoring of the effects of control strategies.

In phase 2 of this project (2008/2009), further surveys were undertaken in March 2009 as follows:

- a survey of Mochrum Loch to record the extent and location of remaining areas of *C. helmsii* requiring treatment, following installation and subsequent removal of WCF
- a survey of the fixed transects to monitor effects of WCF on *C. helmsii* and regeneration of native species.

The timings of the different elements of the overall project are documented in Table 1 (Appendix 2) and methodologies used for phases 1 and 2 of the project are detailed below.

Baseline survey

In phase 1 of the project, surveys of the aquatic macrophytes of Mochrum Loch, Castle Loch and Black Loch were undertaken on 19th and 20th September 2007, 21st September 2007 and 20th September, 2007 respectively. The methods used are documented in ECUS (2013).

Work in Mochrum Loch was undertaken by boat. The survey focused on water up to 1.5 m deep, but also included deeper water, in places where there may be suitable habitat for *C. helmsii*. Macrophytes were recorded from the boat using a bathyscope. As water clarity at the time of survey was good, in order to avoid fragmentation of *C. helmsii,* a grapnel was not used.

The macrophyte surveys of Castle Loch and Black Loch were completed on foot as these water bodies were found to be very shallow close to the shore. Bankside habitat checks for *C. helmsii* on the land surrounding the three water bodies were carried out on foot, or by boat where water levels along the shore line were deep enough and banks too steep to allow safe access on foot.

Resurvey for Crassula helmsii

During phase 2 of the project (2008/09), in order to facilitate future management to suppress *C. helmsii*, survey for this species was undertaken during the removal of WCF (see Section 3.2). Surveyors walked the perimeter of the Loch, surveying both the exposed margins and the littoral areas up to 1 m depth. Further survey by boat was undertaken to detect any *C. helmsii* colonising deeper areas. Using a GPS handset, the occurrence of *C. helmsii* was recorded together with extent where this exceeded 0.25 m^2. For the purposes of calculating

area requiring treatment, areas of colonisation of less than 0.25 m^2 were assumed to cover 0.25 m^2.

Transect vegetation surveys

In phase 1 of the project, locations of six transects, of 10 m in length, were chosen within the Loch during September 2007. Locations of transects were selected to represent a range of habitats within the depth range found to be most affected by *C. helmsii* colonisation in the preceding baseline survey (i.e. 0 - 1 m depth). Where the littoral area was gently shelving, transects extended perpendicular to the shore. Where the littoral area was steeply shelving, transects extended parallel to the shore.

At each transect location, five contiguous 2 m x 2 m quadrats were surveyed and the vegetation present recorded as percentage cover of each quadrat. Percentage bare substrate, substrate composition and average depth for each quadrat were also recorded.

In phase 2 (2008/09), transect surveys were repeated on 17th and 18th March, 2009, in order to monitor the changes in macrophyte communities following implementation of control measures for *C. helmsii*. As expected, in areas where quadrats corresponded to where WCF had been deployed, plant material present was dead and decaying and was not included in the list of species present. Where there was evidence that plants had persisted in a viable state, or were starting to regenerate, these were included in the species composition (e.g. tufts of *Juncus effusus* with green material at the base of the clump, despite the main stems of the plant being rotten or missing). In these areas, an estimate of the cover of dead plant material was also made.

Transect locations are presented in Figure 3 (Appendix 1) and Table 2 (Appendix 2). Digital photographs of each transect location were taken and are presented in Plates 1 to 6 (Appendix 3).

2.2 Control of *Crassula helmsii*

The results of the vegetation surveys in 2007 were used to describe the distribution and abundance of *C. helmsii* in Mochrum Lochs SSSI (Figure 4, Appendix 1). This information was then used to develop management prescriptions aimed at preventing spread of *C. helmsii* and eradication of the species from areas which had been colonised. The aim was to target *C. helmsii*, whilst minimising impacts to native vegetation, so as to encourage recolonisation of treated areas with native species. As *C. helmsii* was recorded only in Mochrum Loch, habitat management prescriptions were made for this water body alone.

Weed Control Fabric

During the surveys of 2007, colonisation by *C. helmsii* was found to be extensive in areas, particularly around the lee shore of the Loch. In these locations, *C. helmsii* dominated the vegetation, with native species being largely excluded. The use of WCF was considered to be the most appropriate option for these areas and was put in place between the 17th and 28th March, 2008. Locations where WCF was deployed are illustrated in Figure 5 (Appendix 1).

Impacts to non-target species, including invertebrate communities, were expected to occur as a result of suppression by the WCF. Therefore, the quantity of WCF used was kept to a minimum, in order to preserve source populations of native species, which would be expected to re-colonise treated areas. WCF was supplied in rolls 3.5 m and 2.5 m wide. Extensively colonised areas were covered most efficiently by the WCF of 3.5 m width and

smaller areas of *C. helmsii* were covered using the WCF of 2.5 m width, to minimise impacts to native species.

Substrate in the photic zone, where *C. helmsii* had become established, is predominantly loose rock, with some areas of soft sediment where peat is carried into the Loch by streams. Soft substrates are also present in areas which are sheltered from the prevailing winds. On both types of substrate, it was found to be impractical to use pegs or stakes to secure WCF to the bed of the Loch. For this reason, large stones were used to secure the fabric and prevent it from moving during the time it was left in place. These stones were taken mainly from the Loch's bed or from the bank, where areas of loose rock were available. In order to minimise physical effort required and to reduce the area affected by the works, these rocks were taken from areas as near to the plants to be covered by fabric as possible.

Where one width of fabric was insufficient to cover a mat of *C. helmsii*, lengths of fabric were placed side by side. In these cases, the fabric was laid to overlap by approximately 0.5 m, with the overlapping area weighed down with stones. WCF was also laid to extend beyond the limit of *C. helmsii* colonisation by approximately 0.5 m. Stones were placed end to end around the perimeter of the fabric and along the joins. This was done in order to prevent light reaching the vegetation below the fabric. Stones were also used to weigh down the centre of fabric lengths, to prevent excessive abrasion of the fabric through wind and wave action. Areas subject to treatment with WCF were recorded using a hand held GPS unit and plotted on a map (Figure 5, Appendix 1), so as to ensure all the WCF was located and removed following the period of shading. Plate 7 (Appendix 3) demonstrates the WCF in place.

During phase 2, removal of fabric was undertaken between 15th and 18th December, 2008, and 2nd and 6th March, 2009, during periods of suitable weather (Plate 8, Appendix 3). Stones used to weigh down the fabric were returned to the lake bed and fabric was folded for transportation. In order to limit the spread of *C. helmsii* from the site, where fragments or patches of viable *C. helmsii* were present on the WCF, every effort was made to remove them before the material was folded for transportation. Fragments of *C. helmsii* were placed on top of terrestrial stands of *C. helmsii*, which were growing in areas out of the zone of wave action, and treated with herbicide.

During removal of the fabric, a patch of long dense stems of *C. helmsii* was found where the plant had escaped between two overlapping sheets of fabric (Plate 9, Appendix 3). This area (approximately 3 m x 2 m) was therefore covered again in WCF weighed down with stones, according to the method described above (Plate 10, Appendix 3).

Reuse of fabric was found to be undesirable, because it was damaged during the initial deployment, as illustrated in Plates 11 and 12 (Appendix 3). Used fabric was disposed of through a local waste management company. A single skip was required to remove the material to a SEPA-registered landfill site. A Controlled Waste Transfer Note was provided by the waste management company, to ensure a safe and traceable disposal route for the fabric.

Herbicide use

Following removal of the WCF from the Loch, spot herbicide treatment of areas of viable *C. helmsii* recorded during the resurvey was undertaken on 19th March and 3rd April, 2009. Herbicide treatment was undertaken by a BASIS-registered and NCPT certified (PA 1 and PA 6) contractor (Neil Dyson, Woodscapes Ltd.). This was carried out when the weather conditions were suitable for spraying herbicide (i.e. dry days with low wind speeds).

Spot application of glyphosate, in the form of Roundup Biactive, was carried out with a knapsack sprayer, using a polijet nozzle, to *C. helmsii* growing in emergent and terrestrial

locations. A total of 150 mL of formulation was used and was applied at a rate of 5 L ha^{-1}, treating an area of approximately 300 m^2. Roundup Biactive is a soluble concentrate containing 360 g L^{-1} glyphosate, present as 480 g L^{-1} (41.1% ww) of the isopropylamine salt of glyphosate.

Spot application of dichlobenil, in the form of Luxan dichlobenil granules, was undertaken in areas where the *C. helmsii* was found growing submerged and in the area of shoreline subject to wave action at the time of treatment. A total of 2.5 kg granules was used. It was applied at a rate of 85 kg ha^{-1}, to treat an area of colonisation by *C. helmsii* of approximately 294 m^2. Luxan dichlobenil granules are a solid granule application of dichlobenil, containing 6.5% dichlobenil ISO (i.e. 65 g kg^{-1}).

Where vegetation was within the area of shoreline subject to wave action at the time of survey, both chemicals were used and therefore the sum of the area treated with each chemical does not represent the total area treated. The area treated using either or both chemicals was estimated to be approximately 440 m^2 in total.

The total area of remaining colonisation by *C. helmsii* was estimated to be less than 360 m^2 (Section 3.1). There was therefore a difference of approximately 80 m^2 between the remaining area covered by *C. helmsii* and the area of habitat treated. This additional area represents the area immediately surrounding each individual plant or patch of *C. helmsii*. Whilst care was taken to minimise herbicide application, an element of over-treatment was necessary to ensure that each patch of *C. helmsii* was fully treated. In addition, when spot-treating such small areas of plant colonisation, the practicalities of application render such over-treatment inevitable.

2.3 Viability testing

The viability of emergent and aquatic plant material which had been shaded was tested by placing it in conditions designed to represent environmental conditions in the field.

Following removal of WCF, samples of apparently dead plant material were taken from the areas it had covered. Due to the heavily decomposed nature of the material, it was not possible to isolate single plants, or to judge reliably which species the material represented. Therefore, six areas of approximately 0.2 m^2 of vegetated substrate were collected from locations which were known to have been heavily colonised by *C. helmsii* and which were representative of the habitat treated with WCF (i.e. emergent and submerged).

Material was collected on the 18th March, 2009 and stored in sealed containers. Sufficient air and moisture were retained within the containers to allow any viable material collected to survive until planting. Shading of the plants by the containers for the short period between collection and planting was not expected to affect the viability of the plant material. Planting was undertaken on 20th March, 2009, as detailed below.

Viability under aquatic conditions

The viability of the plant material found beneath the WCF installed in 2007/2008 was tested by attempting to grow the collected material in seed trays submerged in an outdoor holding tank. The holding tank was situated in an un-shaded position and contained rainwater. Aquatic compost was used to fill three seed trays. Samples of substrate containing plant material were spread evenly across these. Use of aquatic compost ensured sufficient depth of substrate for rooting of plants, without removing excessive amounts of substrate from the Loch. The tops of the trays were secured with bird netting, to help to retain the material within the trays when submerged. Trays were suspended at a depth of 50 cm below the

surface of the water. The top of the tank was covered with bird netting to prevent any possible spread of *C. helmsii* from the site via bird activity.

Seed trays and plant material were left, as described above, for three months, to ensure that any viable material was given the opportunity to establish. The seed trays were examined weekly for signs of plant growth and to check the ambient environmental conditions.

Viability under emergent conditions

The viability of the plant material found beneath the WCF installed in 2007/2008 was tested by attempting to grow the collected material in seed trays in which the water level was maintained around the level of the surface of the substrate, in order to simulate habitat of emergent plants.

The material collected was planted in three seed trays, as detailed for the submerged conditions. These trays were placed in a large tray of a similar depth to the seed trays, which was filled with water. The tray was placed in an un-shaded location outdoors. A wigwam of bird netting was installed over the trays to prevent spread of *C. helmsii* from the site via bird activity. The water level of the tray was monitored to ensure that a representative damp habitat was maintained. However, some fluctuation in water level was allowed, to mimic the natural conditions to which *C. helmsii* would be subjected when growing along the shoreline of a lake.

As for the submerged conditions, seed trays and plant material were left for three months to ensure that any viable material was given the opportunity to establish. The trays were monitored weekly for signs of plant growth and to check culture conditions.

3. RESULTS

3.1 Vegetation survey

Survey of transects

Locations of transects and data from the survey of transects in 2009 are included in Tables 2 and 3 (Appendix 2). Photographs of transect locations are included in Plates 1 to 6 (Appendix 3). Locations of transects are shown in Figure 3 (Appendix 1).

As detailed in Section 2.1, the native macrophyte community was just beginning to emerge following winter senescence at the time of survey and therefore taxonomic features required to identify taxa reliably were not present in many cases. The following list should therefore be considered as indicative. Taxa recorded included *C. helmsii*, willowmoss (*Fontinalis antipyretica*), quillwort (*Isoetes lacustris*), soft rush (*Juncus effusus*), common duckweed (*Lemna minor*), shoreweed (*Littorella uniflora*), water lobelia (*Lobelia dortmanna*), hemlock water-dropwort (*Oenanthe crocata*), reed canary-grass (*Phalaris arundinacea*), curled pondweed (*Potamogeton crispus*), water crowfoot (*Ranunculus* sp.), willow (*Salix* spp.), and bulrush (*Typha latifolia*), along with filamentous and other colonial algae, foliose lichens, mosses and an unidentifiable macrophyte, which was possibly very early shoots of bur-reed (*Sparganium*) or arrowhead (*Sagittaria*) species.

The percentage cover by most species in most quadrats was low, reflecting the emerging nature of the macrophyte community at the time of survey. However, the results of the surveys give some indication of how areas covered by the WCF compared to those left uncovered. Relatively high cover by native plants, such as shoreweed and quillwort, was present in areas which had not been shaded with WCF, i.e. where coverage by *C. helmsii* was low or absent, whereas bare substrate or dead plant material covered the majority of the areas shaded with fabric.

The main purpose of the transect surveys in March 2009 was to allow comparison of percentage cover by *C. helmsii* following shading, with percentage cover observed prior to installing WCF, i.e. to compare present results with those recorded in September 2007. Records of percentage cover in 2007 and 2009 are presented in Table 4 (Appendix 2) for comparison.

All transects but transect 1 were covered by WCF. In areas where WCF was employed, the extent of *C. helmsii* within quadrats was found to have decreased from levels previously recorded. The greatest decrease, from 90 to 0% cover, was noted in quadrat 2, transect 4. In September 2007, in transect 1, *C. helmsii* was present in 3 quadrats, at 5 to 60% cover. In March 2008, no *C. helmsii* was found in this area and, therefore, no WCF was used in this location. However, by March 2009, *C. helmsii* was recolonising the area, and was recorded in 2 quadrats, at 1 to 3% cover.

Resurvey for Crassula helmsii *throughout Mochrum Loch*

Following removal of WCF in March 2009, a survey of the distribution and extent of *C. helmsii* was undertaken throughout the suitable habitat of Mochrum Loch. The locations of occurrences of *C. helmsii*, as recorded using GPS, are shown in Figure 6 (Appendix 1). Grid references and estimates of extent are given in Table 5 (Appendix 2).

Remaining coverage of habitat by *C. helmsii* ranged from small, single plants to larger patches or strips, up to a maximum coverage of an area of approximately 20 m^2. However, areas larger than 10 m^2 were very infrequent and the majority of areas recorded were less

than 0.25 m^2. *C. helmsii* was found both in areas where it had been recorded previously and in areas of the Loch in which it had not been recorded in previous surveys.

In some instances, *C. helmsii* had colonised along the inland edge of a length of fabric and in these locations, the *C. helmsii* was found to be growing in a strip, in soft substrate, along the emergent fringe. At the time of survey, the water level was low and many of the *C. helmsii* plants were not submerged. However, some terrestrial patches of *C. helmsii* recorded at the time of survey exhibited the typical submerged growth form, suggesting that the position was submerged when the material was growing. The remaining occurrences of *C. helmsii* were of small individual clumps found to be rooted in pockets of soft substrate. Plates 13 and 14 (Appendix 3) show *C. helmsii* growing up-shore from the WCF and on top of the WCF, respectively.

The distribution of *C. helmsii* across the littoral zone and shoreline showed different patterns in different areas of the Loch. On the northern two thirds of the west shore and in the north western bay, the majority of the residual *C. helmsii* patches were growing above or on the water line at the time of survey, whereas on the southern third of the west shore, the south shore and the east shore, the majority of residual *C. helmsii* was growing submerged at the time of survey.

The total area which remained colonised by *C. helmsii* was recorded as 359 m^2. This is likely to be a significant over-estimate, as minimum area of cover assumed per record of *C. helmsii*, for the purposes of this calculation, was 0.25 m^2 (to allow for a realistic estimate of the amount of herbicide treatment required), whereas in reality, the majority of the patches of *C. helmsii* marked were much smaller than this.

3.2 Control of *Crassula helmsii*

Weed control fabric

The control of *C. helmsii* by shading using WCF appears to have been successful. No evidence of viable *C. helmsii* was found in areas which had been covered by WCF, except in one area of the north-west bay of the Loch, where *C. helmsii* had escaped between two overlapping sheets of fabric. There, a dense patch of *C. helmsii* comprised of plants with long stems, approximately 3 m x 2 m in area, was observed following removal of the fabric. This area was again covered in WCF.

Following removal of WCF, in areas which had been more densely vegetated, especially by grasses and rushes, a covering of dead and rotting plant material was present. In other locations, bare substrate was found in the shaded areas.

From the results of the previous survey of *C. helmsii* in the Loch in September 2007, when coverage of 1 hectare (10,000 m^2) of habitat by *C. helmsii* was estimated, and those from the survey of residual *C. helmsii* in March 2009, when a coverage of approximately 359 m^2 was estimated, it can be seen that significant control of the species has been achieved, representing a 96% reduction in cover of the habitat at Mochrum Loch.

Photographs showing areas of the Loch's perimeter following removal of WCF are presented in Plates 15 and 16 (Appendix 3).

Herbicide treatment

As the herbicides used have a systemic mode of action (i.e. they are taken up by and translocated within the plant rather than acting on the precise location of contact) it will take

between 2 and 4 weeks for the full effect on the plants to be seen. Therefore the results cannot be judged within the timescale of this stage of the project.

3.3 Viability testing

No regeneration of *C. helmsii* from the vegetation samples taken was observed during the viability trials. Full results of the monitoring are provided in Table 6 (Appendix 2), including data on growing conditions, such as water temperature and pH, and notes on regrowth/establishment of other species.

Small seedlings of other species were observed in the trays which were subject to edge conditions during the viability trials. Some seedlings were observed to grow initially but then failed to establish, whilst others, including grass species, rushes (*Juncus* sp.) starworts (*Callitriche* sp.) and *Ranunculus flammula*/*Alisma* species were seen to establish in the trays by the end of the trials. No growth of higher plants was observed in any of the three submerged trays, however, filamentous algae was observed growing from the trays on the 15th May, 2009 and remained covering the trays until the end of the trial on the 26th June, 2009.

Water temperatures recorded under emergent conditions ranged from 14.9 ^{o}C on the 3rd April, 2009, to 31.0 ^{o}C on the 12th June, 2009. pH recorded under emergent conditions ranged from 7.1 on the 15th May, 2009 to 9.0 on the 29th May, 2009. Water levels simulating edge conditions fluctuated between 1.5 cm above soil level and 1.5 cm below soil level. Water temperatures recorded under submerged conditions ranged from 12.7 ^{o}C on 17th April, 2009 to 29.4 ^{o}C on 12th June, 2009. pH recorded under submerged conditions ranged from 6.8 on 15th May, 2009 to 9.0 on the 24th April, 2009.

4. DISCUSSION

4.1 Success of control measures to date

Caution should be taken when judging the success of the control measures on *C. helmsii* at this stage. Although excellent control appears to have been achieved in areas where WCF was deployed, a definite conclusion on the success of the method cannot be made until the end of the first main growing season (spring and summer 2009). Although the viability testing suggested that the *C. helmsii* which was shaded had died, there remains a possibility the species may yet recover in treated areas following removal of shading.

If the apparent control of *C. helmsii* by the use of WCF has been successful, then the 96% decrease in the cover of the Loch and its shore habitats by the plant will represent a significant step towards controlling or eradicating populations of *C. helmsii* at this site. Essentially, the main areas of infestation have been removed, and remaining, small patches were not well-established and therefore easier to treat using spot herbicide treatments.

The reduction in area of colonisation and therefore biomass of the *C. helmsii* using the shading approach reduced the requirement for herbicide use, with approximately 96% less herbicide required than would have been the case had herbicide been used to treat the infestation at the start of the project.

In addition to the control of the colonisation of Mochrum Loch by *C. helmsii* and the consequent opportunity for recolonisation by native species, the reduction in biomass of the plant around the Loch greatly diminishes the likelihood of the plant spreading to the surrounding wetland habitats and other water bodies, such as Castle Loch and Black Loch.

4.2 Limitations of the control measures

From initial results, the shading approach using WCF has proven effective for treating *C. helmsii* where the plant has established over relatively large areas of shoreline. However, this approach becomes less cost-effective the smaller the areas of *C. helmsii* growth become, as covering many small areas with WCF is more time-consuming and requires a greater area of fabric than blanket shading of the equivalent area as a large block. The blanket shading of large areas to treat small areas of *C. helmsii* would also have a larger relative impact on the native plant community.

In many locations, remaining areas of *C. helmsii* growth were observed in a strip along the shoreward line of the fabric installation, suggesting that higher water levels or wave action had carried fragments of *C. helmsii* above the level of colonisation previously observed. It may be in some cases that the presence of fabric has caused or aided this process. The smooth area of shore resulting from the fabric deployment in the strandline area may have allowed fragments of plants to wash further up the shore by wave action, rather than them catching and lodging in areas of rough substrate.

In future deployments of WCF to treat *C. helmsii*, this possible effect should be taken into account when considering the area to be covered with fabric. It may be worth extending the area covered, so that the edges of the fabric extend beyond the wetted perimeter of the water body. However, this decision would depend upon the profile of the shoreline and the types of substrates present (see Section 4.4), in addition to the requirements of the habitats and native species in the locations concerned.

Where there is very patchy *C. helmsii* growth, spot treatment using herbicide may be more effective as a control option than WCF and, because of the ability to target treatment very efficiently, would be expected to have a limited effect on the native plant community.

However, due to the ban on sale of dichlobenil from March 2009, and subsequent ban on use in or near water from March 2010, the options for herbicide treatment of *C. helmsii* in future will be limited to treatment of emergent or terrestrial vegetation with glyphosate.

As most of the residual *C. helmsii* observed during the survey in March 2009 was above the level of the water, herbicide treatment is expected to remain an integral part of the continued control measures taken. It may also be worth investigating the possibility of lowering water levels if infrastructure for manipulating water levels in the Loch exists, in order to facilitate this treatment. Water levels would have to be drawn down for a period of at least a week. This would allow time for exposed *C. helmsii* to dry, for treatment to be undertaken and the plants to assimilate the glyphosate, before water levels were reinstated.

However, if significant drawdown of the Loch is not possible or desirable, a different approach will have to be taken to prevent submerged areas of *C. helmsii* establishing and again beginning to spread throughout the Loch. In areas where either some or most of the *C. helmsii* growth is submerged, shading would become the best option for treatment, even for relatively small or scattered patches, after March 2010.

The results of the residual *C. helmsii* surveys were used to assess which areas of the Loch required herbicide treatment. The treatment was undertaken by walking the lake margins, spot treating *C. helmsii* wherever it occurred. However, as outlined in Section 4.3, it is very likely that some small areas of *C. helmsii* will have been missed and the herbicide contractor and ecologists undertaking the herbicide treatment agreed an estimate of approximately 80% success in locating and treating existing patches of *C. helmsii*. Areas missed are likely to be extremely small (less than 0.1 m^2) and may not represent successfully established plants, however, the likelihood of regrowth of *C. helmsii* from such areas should be considered when planning future monitoring or control strategies.

4.3 Limitations of survey and monitoring

Limitations of survey

Due to the timing of the transect surveys in March 2009, the data collected are not comparable with the transect survey data gathered in September 2007, and native species should be assumed to be under recorded.

The native macrophyte community was seen to be starting to emerge during the March 2009 surveys, but due to the extremely early growth stage of most plants, definitive identification of the species present was very difficult. An attempt at identification was made to the lowest taxonomic level possible. However, the results should be treated as indicative rather than as a definite record of all species present. As *C. helmsii* continues to grow over the winter months, it may be assumed that the results of the surveys reflect cover by *C. helmsii* more accurately.

Transect surveys

When comparing the results of the quadrat surveys within transects, it should be remembered that without installing fixed point markers within the Loch, it is not possible to guarantee return to exactly the same transect for repeat survey. The error present within GPS systems means that even with good satellite reception, the accuracy of an individual reading should not be presumed to be greater than 5 m. Therefore, any two readings of the same position may vary by up to 10 m, and transect surveys should be viewed as giving an indication of the cover of macrophyte species within the general location of the transect.

As the transects were chosen to represent areas where a high cover of *C. helmsii* was present over extensive areas in September 2007, and the purpose of the March 2009 surveys was primarily to monitor *C. helmsii* cover, this did not necessarily cause a problem when comparing the results of the surveys in September 2007 and March 2009, as a general decline in cover could be presumed from the results. However, monitoring of control measures for smaller areas of *C. helmsii* is required in the long term, so markers should be installed at either end of each transect.

The timing of surveys for macrophyte species is crucial to the accuracy of recording. There have been difficulties with the scheduling of the work of this project, owing to resourcing difficulties, and logistical problems caused by cold and windy weather, teamed with access restraints. Consequently, the surveys carried out in March 2009 were well outside the optimum time for survey of native macrophyte communities. Results therefore cannot be considered to represent accurately the native macrophytes present at the site. A comparison of the results of 2007 and 2009 has therefore not been presented. However, a range of native plants was recorded in 2009, including *I. lacustris*, *L. uniflora* and *L. dortmanna*.

Survey of residual Crassula helmsii

Although the method employed for the survey for residual *C. helmsii* at the Loch was both thorough and appropriate to the situation, it is not realistic to assume that every small patch of *C. helmsii* present within the Loch and its environs was detected.

Any such patches are judged likely to be insignificant in terms of estimation of the size of the area covered by residual *C. helmsii*, due to the probability of patches missed being extremely small, and the overestimation of the area of small patches in the recording system. However, these “missed” areas may be significant in the gradual re-colonisation of the Loch, if monitoring and management of *C. helmsii* does not continue in the medium to long-term.

Viability testing

Although the trials to establish the viability of *C. helmsii* within dead plant material and sediments sampled from beneath WCF were designed to represent submerged and emergent growing conditions, they did not exactly mimic the conditions that would be found in Mochrum Loch. The buffering capacity of water bodies against changes in atmospheric temperature and sunlight are dependent upon the size of the water body, with larger expanses of water lagging behind smaller water bodies in response to changes in atmospheric heat. Thus the fluctuations in water temperature seen in the trial are likely to have been larger than those that would occur in the natural situation at Mochrum Loch.

As temperature has effects on both physical and ecological processes in freshwater, this difference may have resulted in changes in water chemistry and growth patterns. For example, water temperature is a major factor in the growth of algae. High pH values recorded during the trial (up to pH 9 in both emergent and submerged conditions on occasions) were likely to be due to high levels of algal growth resulting from favourable levels of sunlight and water temperature.

However, as *C. helmsii* is known to be a successful coloniser of water bodies of all sizes, from large lakes, to very small, vernal ponds with varying water chemistry, any differences between the trial growing conditions and natural conditions at Mochrum Loch are not thought to be significant with regard to regeneration of *C. helmsii*.

4.4 Distribution and fluctuations in growth and establishment of *Crassula helmsii*

Distribution across hydroseres

The differences in distribution of *C. helmsii* at the Loch in terms of emergent/terrestrial and submerged vegetation are described in Section 3.1. In general, the majority of the *C. helmsii* growing along the north and west shores is in the emergent or terrestrial zones, whereas most of that growing along the south and east shores is fully submerged.

This is most likely to be due to the profile and composition of the shoreline in these locations, with more gradual slope and less coarse substrate along the north-west shore of the Loch, and more steeply-shelving or eroding peat cliff shoreline occurring predominantly along the south and east shores of the Loch. However, the distribution of *C. helmsii* between submerged and terrestrial areas may also reflect the power of the wave action and storms in different areas, according to the most prevalent wind directions, and relative shelter afforded from the wind and waves.

Fluctuations in growth and establishment

When transect 1 was originally surveyed in September 2007, up to 60% cover of *C. helmsii* was recorded in some areas. However, in March 2008, when WCF was deployed, no *C. helmsii* was found in this area and, therefore, no WCF was used in this location.

In the March 2009 transect surveys, small patches of *C. helmsii* were once again observed in this area, however, nothing akin to the previous high extent was recorded. It is not clear whether the original plants observed became dormant and then grew again, or whether this represented a fresh infestation from elsewhere. This area of shore is relatively steeply shelving, straight and exposed, and it may be that *C. helmsii*, although rooting and establishing there, does not find it optimal habitat for the entire year and therefore slips into a cycle of establishment and decline.

This could be linked to the effect of weather and water levels on the habitat, i.e. the plant may grow well there in either low or high water levels and calm conditions, but a change in water levels, possibly teamed with increased wave action caused by storms, may make the area less hospitable to the plant. This pattern may be mirrored on other areas of the Loch shore where habitat conditions are similar.

It must be stressed that this is only conjecture, as a pattern of growth and decline cannot be properly described by two seasons of monitoring and further observation would be required to clarify the situation.

5. RECOMMENDATIONS

A continued programme of monitoring and management of *C. helmsii* at Mochrum Lochs is recommended for 2009.

Ideally, all three lochs should be resurveyed for the presence of *C. helmsii* at the end of the summer 2009 (i.e. late August/September). In Mochrum Loch, this would allow assessment of the effectiveness of control measures undertaken to date, and detection and mapping of any areas of re-growth, or newly established patches of *C. helmsii*. It is important to include Black Loch and Castle Loch in future surveys, to check that *C. helmsii* has not spread to these sites during the period since the original surveys.

The surveys of the macrophyte community at the transect locations should also be repeated at this time, to monitor the recovery of the native plant community.

Removal of the small patch of WCF left in place to treat the area of *C. helmsii* colonisation in the north-west bay could also carried out at this time.

Results of the proposed surveys should be used to inform the requirements for any further control measures to be taken between autumn 2009 and spring 2010.

Late season herbicide treatment can be a good option for control of *C. helmsii*, as the plant continues to grow through the winter months, when native species are senescing, and will therefore take up systemic herbicides more readily than native species at that time. Late season herbicide treatment against any re-growth, or newly established patches of *C. helmsii* recorded during the summer surveys is therefore suggested.

It is recommended that any remaining or newly colonised areas of terrestrial/emergent growth of *C. helmsii* under 10 m^2 detected by the summer surveys should be treated with glyphosate in the autumn months (October/November). Should stocks of dichlobenil which have already been purchased be available, treatment of submerged material using dichlobenil should also be undertaken at this time, according to the label recommendations for use in aquatic situations.

The label instructions for the use of Luxan dichlobenil granules in aquatic situations state, “Apply evenly in spring (March to May) when active growth commences. Treat early in spring to minimise the risk of subsequent water deoxygenating due to the dying back of extensive weed growth.” The product can be used all year round, but in aquatic situations, the quantity of dead, decaying vegetation may cause problems, as the label suggests. Outside the recommended application time, it should therefore only be used in very small areas, not exceeding 10-12% of the total surface area of the water body.

Chemical treatment should be repeated in spring 2010, if any viable areas of *C. helmsii* are found to remain. Treatment should include the use of dichlobenil before 16th March, 2010 (the date of ban on use of the chemical in or near water), should stocks of the chemical purchased before that date be available.

If any substantial areas of *C. helmsii* (e.g. patches greater than 10 m^2 or lengths of shoreline where *C. helmsii* is well-established amongst the native marginal plants, such as rushes) are found to be present by the summer survey, it is suggested that to restrict herbicide use, these areas are subjected to further shading using WCF.

If such measures are necessary, WCF should be deployed in the autumn months, once native plants have set seed and begun to senesce. This timing should help to protect the

seed bank, from which native plants would be expected to recover following removal of the WCF.

Fabric should be left in place for at least 6 months, and viability of plant material under the fabric tested before removal, to check that control of *C. helmsii* has been achieved.

It is recommended that monitoring, of both *C. helmsii* and the native plant population, should be continued over at least a 5-year period, to ensure that control measures have been successful, to inform the need for further control and to assess the recovery of native species. This will help to avoid the situation observed in other SSSIs in the UK, where good initial control of *C. helmsii* and recovery of the native plant communities in the first few years following treatment has been superseded by a gradual reversion to the pre-control condition of the site, after lack of follow-up monitoring and control measures (Kemp & Birkinshaw, 2005; Clarke, 2009).

6. REFERENCES

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Kemp, E. and Birkinshaw, N. 2005. Control of Australian swamp stonecrop *Crassula helmsii* at three designated wetland sites. *Technical report to English Nature*.

Laundon, J.R. 1961. An Australasian species of *Crassula* introduced into Britain. *Watsonia* 5, 59 – 63.

Preston, C.D. and Croft, J.M. 1997. *Aquatic Plants in Britain and Ireland*. Harley Books, Colchester, England, 365 pages.

Willby, N. 2008. Risk assessment of the threat posed by existing populations of New Zealand pygmyweed *Crassula helmsii* in Scotland. *Scottish Natural Heritage Commissioned Report No. 294.*

APPENDIX 1: GIS MAPS

Figure 1. The location of Mochrum Lochs SSSI

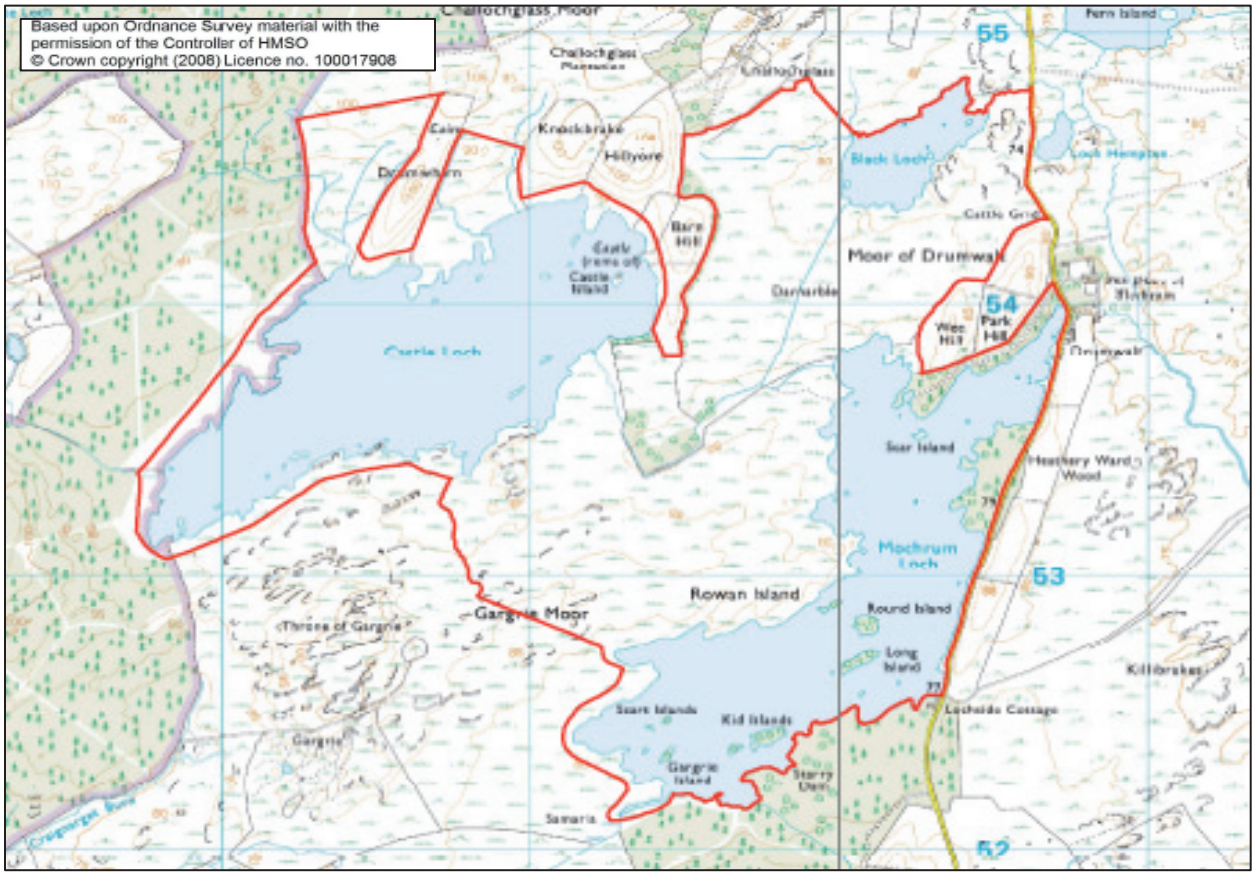

Figure 2. The boundary of Mochrum Lochs SSSI

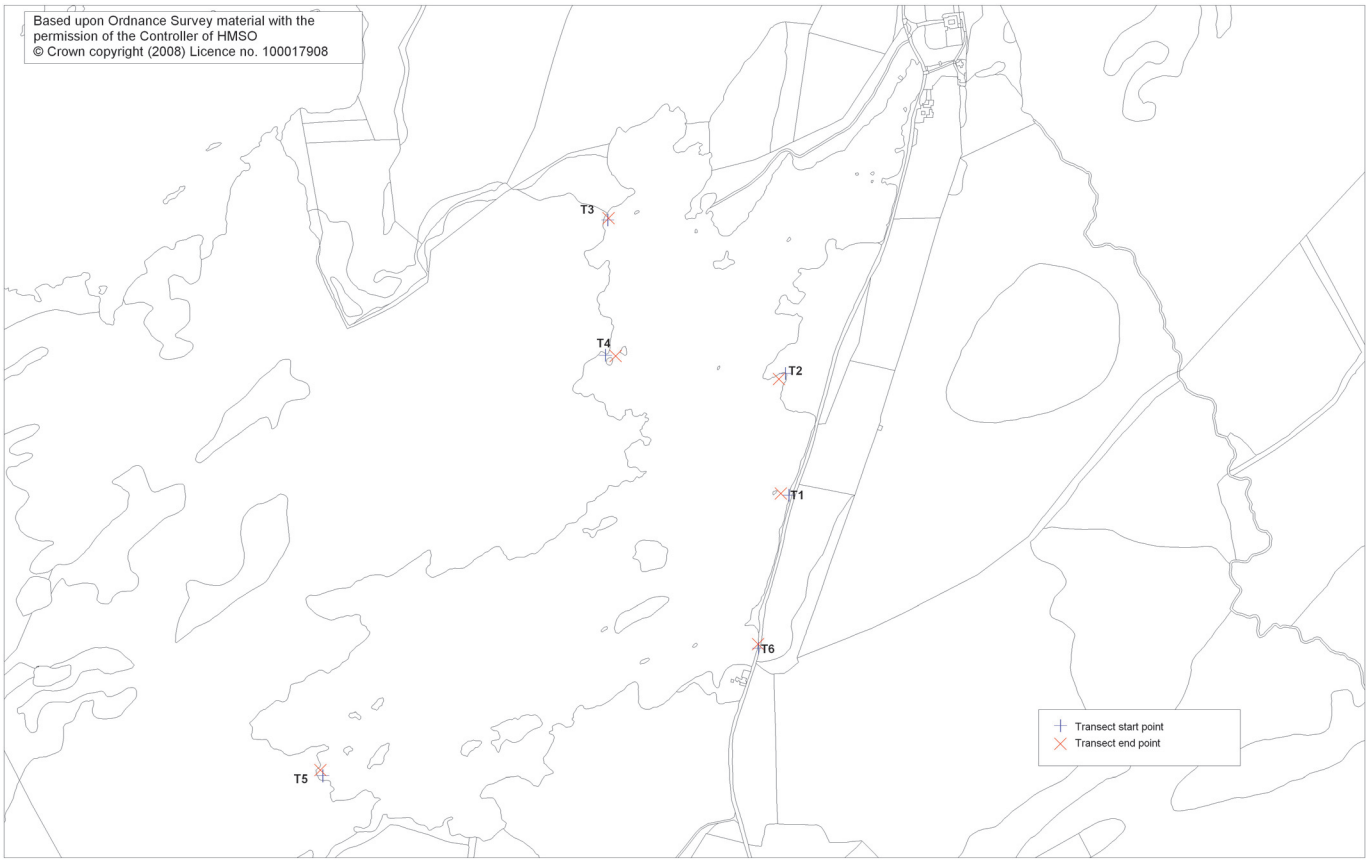

Figure 3. Transect survey locations on Mochrum Loch, March 2009

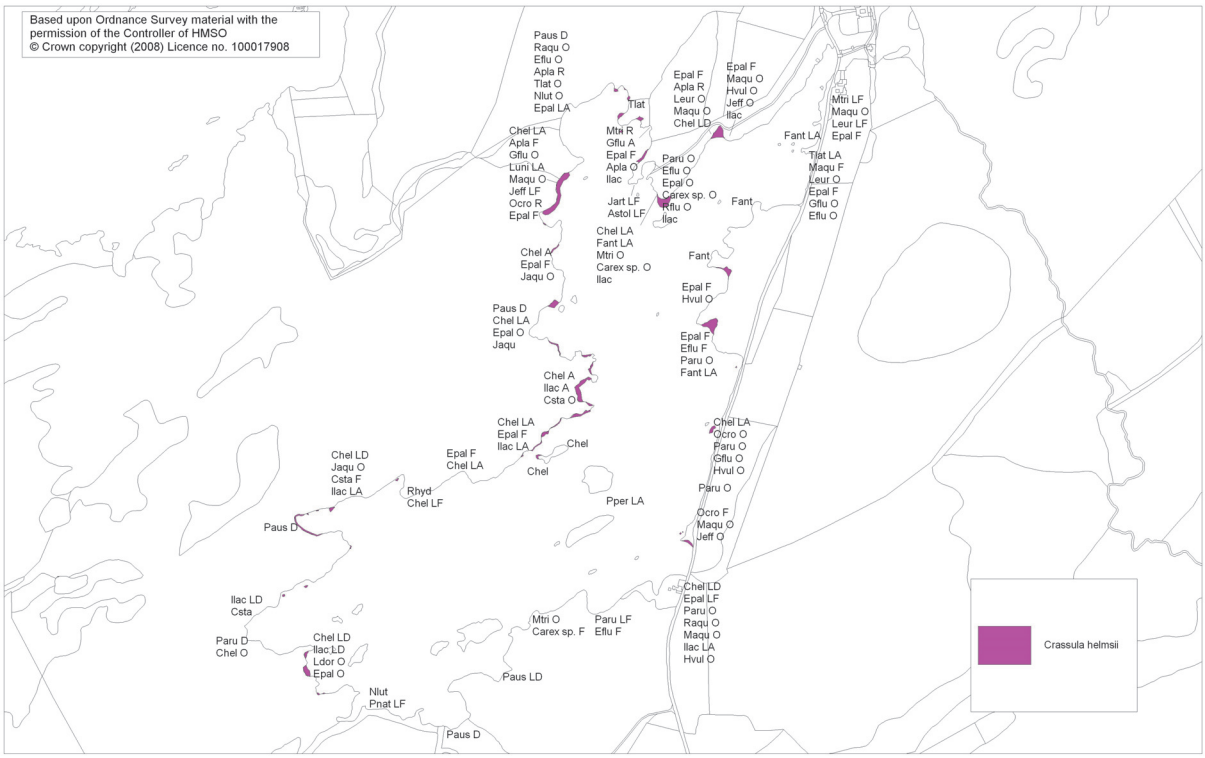

Figure 4. Distribution and abundance of C. helmsii and native macrophyte species in Mochrum Loch, July 2007

Key to codes used in Figure 4

Latin Name	Common Name	Code used
Agrostis stolonifera	Creeping bent	Astol
Alisma plantago-aquatica	Water-plantain	Apla
Callitriche stagnalis	Common water-starwort	Csta
Crassula helmsii	New Zealand pigmy weed	Chel
Eleocharis palustris	Common spike-rush	Epal
Equisetum fluviatile	Water horsetail	Eflu
Fontinalis antipyretica	Willow moss	Fant
Hydrocotyle vulgaris	Marsh pennywort	Hvul
Isoetes lacustris	Quillwort	Ilac
Juncus acutiflorus	Sharp flowered rush	Jaqu
Juncus articulatus	Jointed rush	Jart
Lobelia dortmanna	Water lobelia	Ldor
Nuphar lutea	Yellow water-lily	Nlut
Oenanthe crocata	Hemlock water dropwort	Ocro
Phalaris arundinacea	Reed canary-grass	Paru
Potamogeton natans	Broadleaved pondweed	Pnat
Potamogeton perfoliatus	Perfoliate pondweed	Pper
Ranunculus aquatilis	Common water-crowfoot	Raqu
Typha latifolia	Bulrush	Tlat
Juncus effusus	Soft rush	Jeff
Mentha aquatic	Water mint	Maqu
Menyanthes trifoliata	Bog bean	Mtri
Lycopus europeaus	Gypsywort	Leur
Rumex hydrolapthum	Water dock	Rhyd
Littorella uniflora	Shoreweed	Luni
Ranunculus flammula	Lesser spearwort	Rflu
Phragmites australis	Common reed	Paus
Glyceria fluitans	Floating sweet-grass	Gflu

DAFOR scale

D - dominant

A - abundant

F - frequent

O - occasional

R - rare

L – indicates local distribution e.g. LA - locally abundant

DAFOR ratings refer to general areas in which species were found and are not limited to areas in which *C.helmsii* was present.

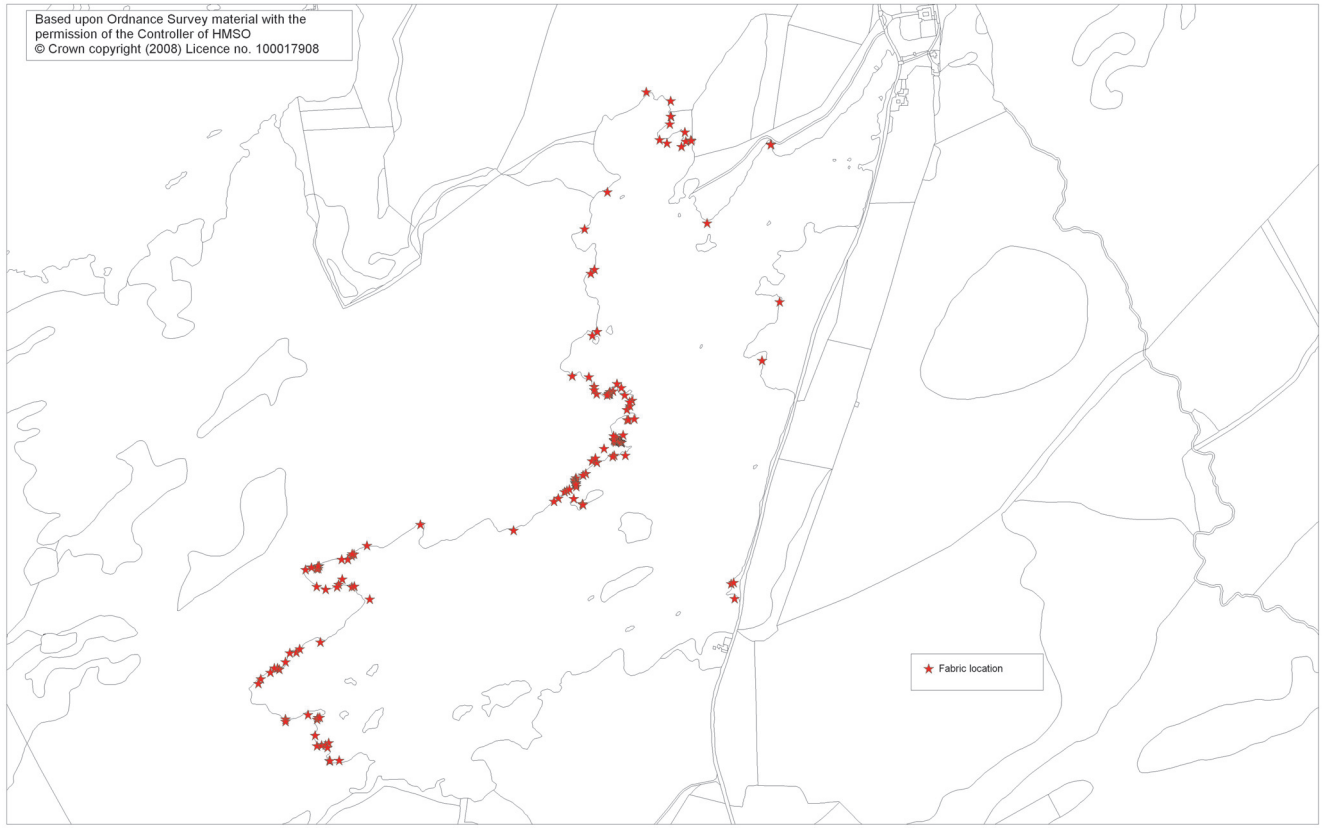

Figure 5. Locations of Weed Control Fabric deployed at Mochrum Loch, March 2008

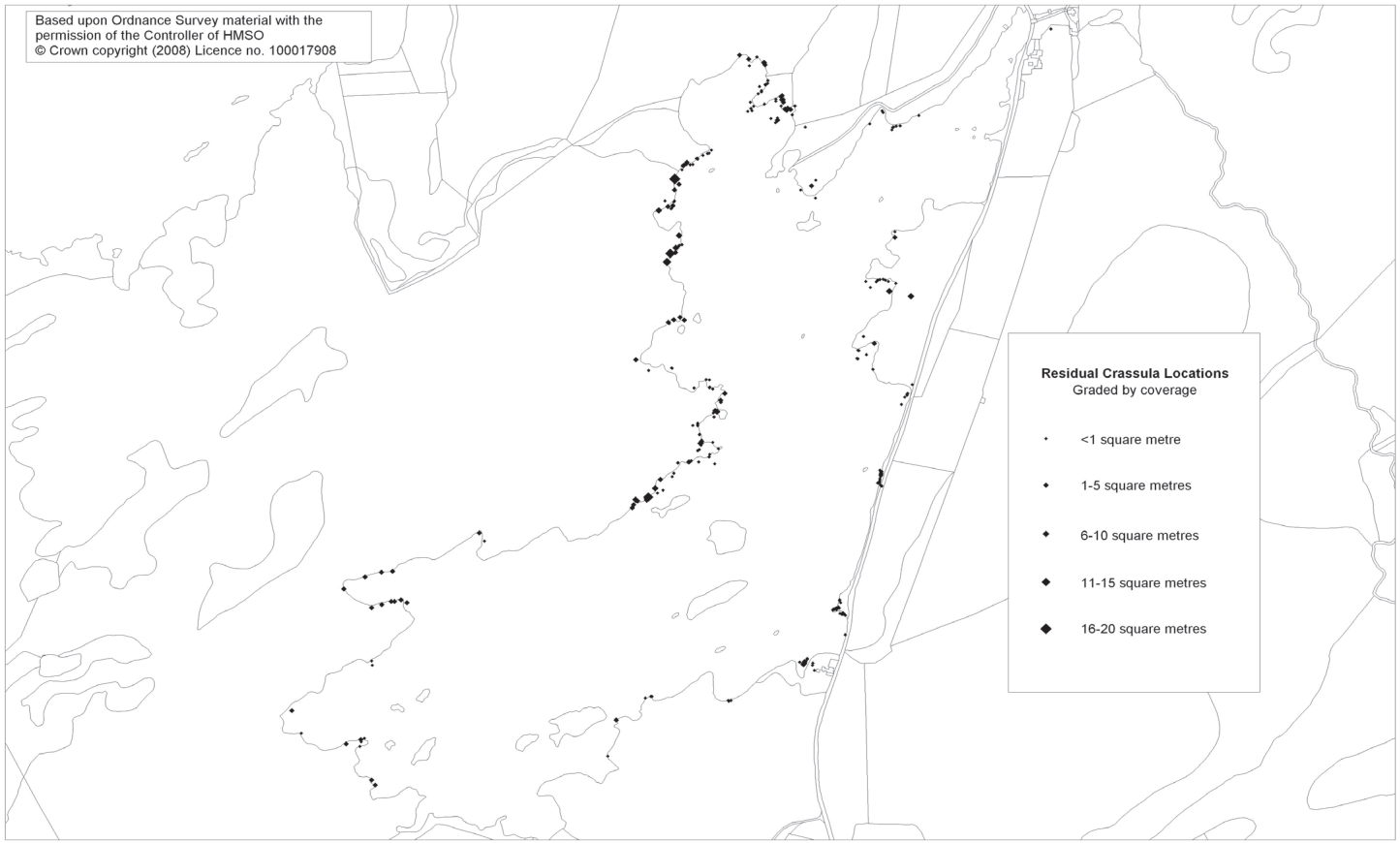

Figure 6. Locations of remaining Crassula helmsii*, March 2009*

APPENDIX 2: TABLES

Table 1. Phases of the programme of survey and control of C. helmsii at Mochrum Lochs SSSI

Task	Date
Baseline aquatic vegetation survey of Mochrum Loch, Castle Loch and Black Loch	September 2007
Initial transect surveys, Mochrum Loch	September 2007
Installation of weed control fabric on Mochrum Loch	March 2008
Removal of weed control fabric from Mochrum Loch	December 2008 and March 2009
Residual *C. helmsii* survey on Mochrum Loch	March 2009
Repeat transect survey on Mochrum Loch	March 2009
Spot herbicide application on Mochrum Loch	March and April 2009

Table 2. Locations of quadrats in transects in Mochrum Loch, 2009

Transects	Start point		End point		Survey Date
	X	Y	X	Y	
1	230418.93	552965.26	230399.58	552970.56	17/03/2009
2	230410.81	553254.14	230395.20	553241.55	17/03/2009
3	229987.69	553618.13	229989.0	553623.0	18/03/2009
4	229987.0	553618.0	230006.05	553296.90	18/03/2009
5	229309.97	552299.14	229303.71	552313.06	18/03/2008
6	230346.00	552602.00	230345.00	552612.00	18/03/2008

Table 3. Percentage cover by macrophytes, information on substrate and water depth in transects in Mochrum Loch, 2009

Transect number	1				
Transect type	Shore perpendicular				
Survey date	17/03/2009				
Photograph number	68				
Transect start	NX3041852965				
Transect end	NX3039952970				
	Quadrat				
Species	**1**	**2**	**3**	**4**	**5**
Crassula helmsii	3	1			
Filamentous green algae					
Foliose lichen species					
Fontinalis antipyretica	<1				
Green algae agg.					
Isoetes lacustris			5	5	50
Juncus effusus					
Lemna minor					
Littorella uniflora	10	5	3		<0.1
Lobelia dortmanna					
Moss species					
Oenanthe crocata	<1				
Phalaris arundinacea					
Potamogeton crispus					
Ranunculus species (*aquatilis* ?)		<1	<0.1		
Salix species					
Sparganium/*Sagittaria* ? (very small young plants)			<0.1		
Typha latifolia					
Substrate (%)					
Silt					45
Sand	5	20	30	69	40
Gravel	80	8	2		
Pebble	5	30	6	3	
Cobble	5	40	30	3	
Boulder	5	2	2	5	5
Bedrock			30	20	10
Water depth (m)	0.15	0.3	0.6	0.8	0.9
% bare substrate	87	94	92	95	50

Transect number	2				
Transect type	Shore perpendicular				
Survey date	17/03/2009				
Photograph number	60 & 61				
Transect start	NX3041053254				
Transect end	NX3039553241				
	Quadrat				
Species	**1**	**2**	**3**	**4**	**5**
Crassula helmsii					
Filamentous green algae			<0.1		
Foliose lichen species					
Fontinalis antipyretica					
Green algae agg.					<0.1
Isoetes lacustris					
Juncus effusus		7			
Lemna minor		<0.1			
Littorella uniflora					
Lobelia dortmanna					
Moss species					
Oenanthe crocata					
Phalaris arundinacea	10			10	
Potamogeton crispus					
Ranunculus species (*aquatilis* ?)					
Salix species		1			
Sparganium/*Sagittaria* ? (very small young plants)					
Typha latifolia	2				
Substrate					
Silt	99	95	50		
Sand					
Gravel					
Pebble			15	8	70
Cobble			30	90	30
Boulder			5	2	
Bedrock	1	5			
Water depth (m)	0	0	0.025	0.25	0.25
% bare substrate	50	42	70	90	100
% dead plant	38	50	30	0	0

Transect number	3				
Transect type	Shore parallel				
Survey date	18/02/2009				
Photograph number	76				
Transect start	NX2998753618				
Transect end	NX2998953623				
	Quadrat				
Species	**1**	**2**	**3**	**4**	**5**
Crassula helmsii	<1	<0.1	<0.1		1
Filamentous green algae					
Foliose lichen species					
Fontinalis antipyretica	<1	<0.1			
Green algae agg.					
Isoetes lacustris					
Juncus effusus	<1			<1	<0.1
Lemna minor					
Littorella uniflora	<0.1				
Lobelia dortmanna					
Moss species	1	1	1	1	
Oenanthe crocata					
Phalaris arundinacea					
Potamogeton crispus					
Ranunculus species (*aquatilis* ?)					
Salix species					
Sparganium/*Sagittaria* ? (very small young plants)			<0.1		
Typha latifolia					
Substrate					
Silt	10	5	20	50	60
Sand	25	20	10	19	
Gravel	15	10	5	1	
Pebble	25	40	20	5	5
Cobble	5	10	20	15	15
Boulder	5	10	10	5	15
Bedrock	15	5	15	5	5
Water depth (m)	0.2	0.25	0.3	0.2	0.2
% bare substrate	98	99	99	99	99

Transect number	4				
Transect type	Shore perpendicular				
Survey date	18/03/2009				
Photograph number	84				
Transect start	NX2998253297				
Transect end	NX3000653296				
	Quadrat				
Species	**1**	**2**	**3**	**4**	**5**
Crassula helmsii	1				
Filamentous green algae					
Foliose lichen species					
Fontinalis antipyretica			<1	3	<1
Green algae agg.					
Isoetes lacustris					
Juncus effusus	1				
Lemna minor					
Littorella uniflora		1	4	3	1
Lobelia dortmanna	<0.1	<0.1	<0.1	<0.1	<0.1
Moss species	<1				
Oenanthe crocata					
Phalaris arundinacea					
Potamogeton crispus					
Ranunculus species (*aquatilis* ?)					
Salix species					
Sparganium/*Sagittaria* ? (very small young plants)	3	80			
Typha latifolia					
Substrate					
Silt	80	90	60	60	90
Sand					
Gravel					
Pebble	10				
Cobble	10	5			
Boulder		5	10	20	5
Bedrock			30	20	5
Water depth (m)	0.3	0.4	0.5	0.5	0.5
% bare substrate	95	19	96	94	99

Transect number	5				
Transect type	Shore perpendicular				
Survey date	18/03/2009				
Photograph number	85				
Transect start	NX2930952299				
Transect end	NX2930352313				
	Quadrat				
Species	**1**	**2**	**3**	**4**	**5**
Crassula helmsii					
Filamentous green algae					
Foliose lichen species					
Fontinalis antipyretica				<0.1	
Green algae agg.					
Isoetes lacustris			1	3	
Juncus effusus					
Lemna minor					
Littorella uniflora	5	5	60	40	90
Lobelia dortmanna					
Moss species					
Oenanthe crocata					
Phalaris arundinacea					
Potamogeton crispus				<0.1	
Ranunculus species (*aquatilis* ?)				<0.1	
Salix species					
Sparganium/*Sagittaria ?* (very small young plants)					
Typha latifolia					
Substrate					
Silt	100	100	99	100	100
Sand					
Gravel					
Pebble					
Cobble					
Boulder					
Bedrock			1		
Water depth (m)	0.3	0.4	0.5	0.5	0.4
% bare substrate	95	95	39	57	10

Transect number	6				
Transect type	Shore parallel				
Survey date	18/03/2009				
Photograph number	86				
Transect start	NX3034652602				
Transect end	NX3034552612				
	Quadrat				
Species	**1**	**2**	**3**	**4**	**5**
Crassula helmsii	<1	<1			
Filamentous green algae					
Foliose lichen species					<0.1
Fontinalis antipyretica					<0.1
Green algae agg.					
Isoetes lacustris					
Juncus effusus					
Lemna minor					
Littorella uniflora	<1	1	4	<1	3
Lobelia dortmanna					
Moss species					
Oenanthe crocata	1	3	3		1
Phalaris arundinacea	5	3	5	<1	5
Potamogeton crispus					
Ranunculus species (*aquatilis* ?)					
Salix species.					
Sparganium/*Sagittaria* ? (very small young plants)					
Typha latifolia					
Substrate					
Silt					
Sand	35	30	10	5	3
Gravel	40	25	10	5	2
Pebble	20	20	45	35	20
Cobble		5	5	5	25
Boulder	5	20	30	50	50
Bedrock					
Water depth (m)	0.1	0.15	0.2	0.25	0.1
% bare substrate	94	93	88	100	91

Table 4. Percentage cover of quadrats by C. helmsii in September 2007 and March 2009

	Quadrat number									
	September 2007					March 2009				
Transect	1	2	3	4	5	1	2	3	4	5
1	60	35	5	0	0	3	1	0	0	0
2	90	90	70	35	20	0	0	0	0	0
3	85	95	95	85	75	1	0.1	0.1	0	0
4	90	90	75	10	0	1	0	0	0	0
5	75	55	70	65	45	0	0	0	0	0
6	45	45	65	25	25	1	1	0	0	0

Table 5. C. helmsii remaining after removal of weed control fabric

Position	Easting	Northing	Extent of *Crassula helmsii* (m^2)
NX 30419 52936	230419	552936	<0.25
NX 30418 52937	230418	552937	<0.25
NX 30416 52938	230416	552938	<0.25
NX 30410 52943	230410	552943	<0.25
NX 30411 52943	230411	552943	<0.25
NX 30411 52943	230411	552943	<0.25
NX 30412 52943	230412	552943	<0.25
NX 30413 52944	230413	552944	<0.25
NX 30414 52944	230414	552944	0.25
NX 30413 52944	230413	552944	<0.25
NX 30414 52945	230414	552945	<0.25
NX 30413 52945	230413	552945	<0.25
NX 30415 52949	230415	552949	<0.25
NX 30415 52949	230415	552949	<0.25
NX 30415 52952	230415	552952	<0.25
NX 30416 52957	230416	552957	<0.25
NX 30418 52959	230418	552959	<0.25
NX 30417 52961	230417	552961	3
NX 30416 52965	230416	552965	<0.25
NX 30416 52962	230416	552962	<0.25
NX 30417 52963	230417	552963	<0.25
NX 30417 52964	230417	552964	<0.25
NX 30419 52965	230419	552965	<0.25
NX 30418 52967	230418	552967	<0.25
NX 30417 52968	230417	552968	<0.25
NX 30417 52968	230417	552968	<0.25
NX 30416 52969	230416	552969	<0.25
NX 30419 52969	230419	552969	<0.25
NX 30415 52972	230415	552972	0.3
NX 30461 53118	230461	553118	<0.25
NX 30468 53134	230468	553134	0.25
NX 30473 53138	230473	553138	<0.25
NX 30473 53140	230473	553140	<0.25
NX 30474 53142	230474	553142	<0.25
NX 30780 53952	230780	553952	<0.25
NX 30498 53760	230498	553760	<0.25
NX 30441 53728	230441	553728	<0.25
NX 30442 53733	230442	553733	<0.25
NX 30443 53734	230443	553734	<0.25
NX 30444 53734	230444	553734	<0.25
NX 30458 53737	230458	553737	<0.25

NX 30450 53736	230450	553736	<0.25
NX 30422 53766	230422	553766	<0.25
NX 30421 53767	230421	553767	<0.25
NX 30420 53770	230420	553770	<0.25
NX 30393 53741	230393	553741	<0.25
NX 30329 52683	230329	552683	<0.25
NX 30329 52682	230329	552682	<0.25
NX 30331 52677	230331	552677	<0.25
NX 30328 52665	230328	552665	<0.25
NX 30326 52668	230326	552668	<0.25
NX 30327 52666	230327	552666	<0.25
NX 30318 52662	230318	552662	<0.25
NX 30317 52662	230317	552662	<0.25
NX 30316 52663	230316	552663	<0.25
NX 30314 52661	230314	552661	<0.25
NX 30330 52653	230330	552653	<0.25
NX 30334 52651	230334	552651	<0.25
NX 30341 52650	230341	552650	<0.25
NX 30341 52649	230341	552649	<0.25
NX 30341 52606	230341	552606	<0.25
NX 30275 52527	230275	552527	<0.25
NX 30271 52538	230271	552538	<0.25
NX 30272 52543	230272	552543	<0.25
NX 30260 52551	230260	552551	<0.25
NX 30260 52553	230260	552553	<0.25
NX 30257 52546	230257	552546	<0.25
NX 30254 52544	230254	552544	<0.25
NX 30254 52546	230254	552546	2
NX 30252 52543	230252	552543	1.5
NX 30253 52542	230253	552542	0.25
NX 30252 52541	230252	552541	<0.25
NX 30244 52545	230244	552545	<0.25
NX 30251 52540	230251	552540	4
NX 30252 52539	230252	552539	3
NX 30254 52542	230254	552542	2
NX 30097 52460	230097	552460	<0.25
NX 30092 52458	230092	552458	<0.25
NX 30092 52459	230092	552459	<0.25
NX 30091 52460	230091	552460	<0.25
NX 29928 52469	229928	552469	0.25
NX 29926 52469	229926	552469	0.25
NX 29926 52469	229926	552469	<0.25
NX 29914 52465	229914	552465	<0.25
NX 29853 52416	229853	552416	0.25
NX 29852 52416	229852	552416	4
NX 29834 52336	229834	552336	0.25

NX 30115 53894	230115	553894	1
NX 30135 53885	230135	553885	1
NX 30136 53870	230136	553870	<0.25
NX 30152 53890	230152	553890	<0.25
NX 30167 53877	230167	553877	1
NX 30168 53877	230168	553877	1
NX 30170 53872	230170	553872	1
NX 30176 53837	230176	553837	<0.25
NX 30175 53831	230175	553831	<0.25
NX 30158 53824	230158	553824	<0.25
NX 30170 53828	230170	553828	<0.25
NX 30172 53828	230172	553828	<0.25
NX 30155 53808	230155	553808	<0.25
NX 30162 53812	230162	553812	<0.25
NX 30162 53815	230162	553815	<0.25
NX 30133 53769	230133	553769	<0.25
NX 30142 53770	230142	553770	<0.25
NX 30140 53775	230140	553775	<0.25
NX 30140 53775	230140	553775	<0.25
NX 30145 53780	230145	553780	<0.25
NX 30138 53789	230138	553789	<0.25
NX 30168 53785	230168	553785	<0.25
NX 30193 53791	230193	553791	<0.25
NX 30204 53802	230204	553802	3
NX 30206 53804	230206	553804	1
NX 30193 53796	230193	553796	<0.25
NX 30205 53795	230205	553795	<0.25
NX 30206 53795	230206	553795	3
NX 30207 53795	230207	553795	10
NX 30209 53789	230209	553789	1
NX 30204 53781	230204	553781	<0.25
NX 30182 53753	230182	553753	<0.25
NX 30216 53771	230216	553771	2
NX 30218 53776	230218	553776	2
NX 30228 53761	230228	553761	<0.25
NX 30196 53748	230196	553748	<0.25
NX 30196 53749	230196	553749	3
NX 30195 53749	230195	553749	<0.25
NX 30192 53744	230192	553744	<0.25
NX 30196 53754	230196	553754	<0.25
NX 30212 53774	230212	553774	2
NX 30225 53772	230225	553772	<0.25
NX 30224 53773	230224	553773	2
NX 30234 53781	230234	553781	<0.25
NX 30233 53781	230233	553781	<0.25
NX 30256 53734	230256	553734	<0.25

NX 30246 53594	230246	553594	<0.25
NX 30278 53616	230278	553616	<0.25
NX 30269 53605	230269	553605	<0.25
NX 30269 53603	230269	553603	3
NX 30277 53576	230277	553576	<0.25
NX 29935 52931	229935	552931	9
NX 29952 52927	229952	552927	<0.25
NX 29940 52921	229940	552921	<0.25
NX 29920 52912	229920	552912	20
NX 29921 52913	229921	552913	<0.25
NX 29920 52914	229920	552914	<0.25
NX 29914 52908	229914	552908	<0.25
NX 29893 52906	229893	552906	6
NX 29889 52895	229889	552895	2
NX 29971 52957	229971	552957	<0.25
NX 29975 52965	229975	552965	<0.25
NX 29983 52988	229983	552988	<0.25
NX 29984 52988	229984	552988	<0.25
NX 30012 52993	230012	552993	<0.25
NX 30028 52990	230028	552990	<0.25
NX 30029 53017	230029	553017	<0.25
NX 30026 53015	230026	553015	<0.25
NX 30062 52986	230062	552986	<0.25
NX 30050 53001	230050	553001	<0.25
NX 30052 53007	230052	553007	<0.25
NX 30070 53019	230070	553019	<0.25
NX 30058 53033	230058	553033	<0.25
NX 30033 53027	230033	553027	<0.25
NX 30031 53032	230031	553032	<0.25
NX 30032 53031	230032	553031	9
NX 30034 53036	230034	553036	5
NX 30030 53051	230030	553051	<0.25
NX 30029 53051	230029	553051	<0.25
NX 30026 53073	230026	553073	<0.25
NX 30026 53070	230026	553070	<0.25
NX 30015 53071	230015	553071	<0.25
NX 30026 53076	230026	553076	<0.25
NX 30061 53090	230061	553090	<0.25
NX 30059 53099	230059	553099	<0.25
NX 30064 53103	230064	553103	1
NX 30063 53104	230063	553104	2
NX 30067 53102	230067	553102	10
NX 30075 53127	230075	553127	1
NX 30075 53122	230075	553122	<0.25
NX 30076 53123	230076	553123	<0.25
NX 30084 53142	230084	553142	1

NX 30058 53152	230058	553152	<0.25
NX 30051 53155	230051	553155	<0.25
NX 30051 53155	230051	553155	<0.25
NX 30052 53156	230052	553156	<0.25
NX 30051 53172	230051	553172	<0.25
NX 30044 53173	230044	553173	<0.25
NX 30018 53154	230018	553154	<0.25
NX 29894 53217	229894	553217	3
NX 29921 53193	229921	553193	<0.25
NX 29970 53199	229970	553199	<0.25
NX 29971 53198	229971	553198	<0.25
NX 29975 53306	229975	553306	5
NX 29965 53297	229965	553297	<0.25
NX 29965 53297	229965	553297	<0.25
NX 29988 53311	229988	553311	1
NX 29962 53300	229962	553300	<0.25
NX 29963 53300	229963	553300	5
NX 29997 53305	229997	553305	1
NX 29960 53434	229960	553434	12
NX 29967 53453	229967	553453	16
NX 29977 53454	229977	553454	<0.25
NX 29978 53455	229978	553455	<0.25
NX 29978 53455	229978	553455	5
NX 29979 53466	229979	553466	6
NX 29985 53470	229985	553470	<0.25
NX 29987 53471	229987	553471	<0.25
NX 29992 53473	229992	553473	<0.25
NX 29986 53493	229986	553493	6
NX 29943 53549	229943	553549	7
NX 29956 53570	229956	553570	<0.25
NX 29962 53557	229962	553557	2
NX 29969 53552	229969	553552	<0.25
NX 29969 53553	229969	553553	<0.25
NX 29973 53559	229973	553559	1
NX 29975 53568	229975	553568	<0.25
NX 29976 53570	229976	553570	<0.25
NX 29976 53594	229976	553594	1
NX 29986 53607	229986	553607	1
NX 29979 53616	229979	553616	1
NX 29976 53622	229976	553622	10
NX 29995 53647	229995	553647	<0.25
NX 29996 53651	229996	553651	<0.25
NX 30003 53656	230003	553656	3
NX 30002 53653	230002	553653	1
NX 30001 53653	230001	553653	<0.25
NX 30003 53654	230003	553654	<0.25

NX 29977 53619	229977	553619	25
NX 29992 53639	229992	553639	<0.25
NX 29995 53648	229995	553648	5
NX 30010 53650	230010	553650	<0.25
NX 30015 53651	230015	553651	<0.25
NX 30023 53664	230023	553664	<0.25
NX 30025 53665	230025	553665	<0.25
NX 30037 53671	230037	553671	<0.25
NX 30047 53675	230047	553675	<0.25
NX 30050 53676	230050	553676	<0.25
NX 30055 53683	230055	553683	<0.25
NX 30026 53663	230026	553663	<0.25
NX 30336 52653	230336	552653	5
NX 30322 52664	230322	552664	2
NX 30319 52664	230319	552664	<0.25
NX 30319 52664	230319	552664	<0.25
NX 30484 53162	230484	553162	<0.25
NX 30400 53195	230400	553195	<0.25
NX 30368 53219	230368	553219	<0.25
NX 30366 53220	230366	553220	<0.25
NX 30403 53254	230403	553254	<0.25
NX 30403 53253	230403	553253	5
NX 30386 53228	230386	553228	<0.25
NX 30370 53237	230370	553237	<0.25
NX 30368 53238	230368	553238	<0.25
NX 30380 53269	230380	553269	<0.25
NX 30395 53378	230395	553378	<0.25
NX 30435 53369	230435	553369	9
NX 30481 53358	230481	553358	9
NX 30433 53391	230433	553391	<0.25
NX 30427 53394	230427	553394	<0.25
NX 30449 53387	230449	553387	<0.25
NX 30422 53396	230422	553396	<0.25
NX 30415 53395	230415	553395	<0.25
NX 30410 53394	230410	553394	<0.25
NX 30409 53392	230409	553392	<0.25
NX 30407 53390	230407	553390	<0.25
NX 30385 53391	230385	553391	<0.25
NX 30447 53489	230447	553489	1
NX 30446 53488	230446	553488	<0.25
NX 30446 53488	230446	553488	<0.25
NX 30446 53488	230446	553488	<0.25
NX 30447 53501	230447	553501	<0.25
NX 29337 52272	229337	552272	1
NX 29329 52283	229329	552283	1
NX 29304 52358	229304	552358	<0.25

NX 29307 52368	229307	552368	<0.25
NX 29314 52376	229314	552376	<0.25
NX 29306 52373	229306	552373	1
NX 29275 52363	229275	552363	2
NX 29179 52387	229179	552387	<0.25
NX 29159 52437	229159	552437	1
NX 29331 52538	229331	552538	<1
NX 29329 52548	229329	552548	<0.25
NX 29405 52677	229405	552677	1
NX 29392 52683	229392	552683	1
NX 29378 52680	229378	552680	1
NX 29371 52680	229371	552680	1
NX 29351 52673	229351	552673	2
NX 29329 52666	229329	552666	2
NX 29270 52708	229270	552708	1
NX 29315 52734	229315	552734	3
NX 29350 52745	229350	552745	1
NX 29374 52747	229374	552747	3
NX 29559 52832	229559	552832	1
NX 29570 52814	229570	552814	<0.25
NX 29886 52888	229886	552888	1
NX 29897 52903	229897	552903	2
NX 29917 52905	229917	552905	4
NX 29946 52951	229946	552951	2
NX 30007 52990	230007	552990	2

Table 6. C. helmsii growth trial monitoring data

Sample	Treatment	Monitoring date	Water temperature (°C)	pH	Regeneration of *C. helmsii*	Notes
1	Submerged	27/03/2009	14.8	8.8	No	n/a
2	Emergent	27/03/2009	22.7	7.5	No	Seedlings growing, not *C. helmsii*
3	Submerged	27/03/2009	14.8	8.8	No	n/a
4	Emergent	27/03/2009	22.7	7.5	No	n/a
5	Submerged	27/03/2009	14.8	8.8	No	n/a
6	Emergent	27/03/2009	22.7	7.5	No	Seedlings growing, not *C. helmsii*
1	Submerged	03/04/2009	15.8	8.7	No	n/a
2	Emergent	03/04/2009	14.9	8.1	No	More seedlings growing, not *C. helmsii*
3	Submerged	03/04/2009	15.8	8.7	No	n/a
4	Emergent	03/04/2009	14.9	8.1	No	Seedlings growing, not *C. helmsii*. Some grass seedlings present.
5	Submerged	03/04/2009	15.8	8.7	No	n/a
6	Emergent	03/04/2009	14.9	8.1	No	Seedlings growing, not C. helmsii
1	Submerged	10/04/2009	17.0	8.8	No	n/a
2	Emergent	10/04/2009	17.0	7.5	No	Some *Callitriche* sp seedlings identified
3	Submerged	10/04/2009	17.0	8.8	No	n/a
4	Emergent	10/04/2009	17.0	7.5	No	Seedlings still present
5	Submerged	10/04/2009	17.0	8.8	No	n/a
6	Emergent	10/04/2009	17.0	7.5	No	*Agrostis stolonifera* appears to be regenerating
1	Submerged	17/04/2009	12.7	8.2	No	n/a
2	Emergent	17/04/2009	16.0	7.7	No	Some seedlings establishing – possibly *Callitriche*
3	Submerged	17/04/2009	12.7	8.2	No	n/a
4	Emergent	17/04/2009	16.0	7.7	No	some seedlings including grasses present
5	Submerged	17/04/2009	12.7	8.2	No	n/a
6	Emergent	17/04/2009	16.0	7.7	No	No growth noted
1	Submerged	24/04/2009	14.3	9.0	No	n/a
2	Emergent	24/04/2009	15.2	8.3	No	Some seedlings establishing – possibly *Callitriche*
3	Submerged	24/04/2009	14.3	9.0	No	n/a
4	Emergent	24/04/2009	15.2	8.3	No	Some seedlings established, grass seedlings developing well
5	Submerged	24/04/2009	14.3	9.0	No	n/a
6	Emergent	24/04/2009	15.2	8.3	No	Some small grass seedlings and other herb seedlings

1	Submerged	01/05/2009	22.7	8.9	No	n/a
2	Emergent	01/05/2009	24.9	8.3	No	Seedlings growing, grass and possibly *Callitriche*
3	Submerged	01/05/2009	22.7	8.9	No	n/a
4	Emergent	01/05/2009	24.9	8.3	No	Grass seedlings developing
5	Submerged	01/05/2009	22.7	8.9	No	n/a
6	Emergent	01/05/2009	24.9	8.3	No	Some grass and herb seedling present
1	Submerged	15/05/2009	15.4	6.8	No	Filamentous green algae growing on trays
2	Emergent	15/05/2009	16.0	7.1	No	Grass and *Callitriche* growing
3	Submerged	15/05/2009	15.4	6.8	No	Filamentous green algae growing on trays
4	Emergent	15/05/2009	16.0	7.1	No	Grass well developed, some other herbs present
5	Submerged	15/05/2009	15.4	6.8	No	Filamentous green algae growing on trays
6	Emergent	15/05/2009	16.0	7.1	No	Grass and herbs growing, poss. *Ranunculus flammula*
1	Submerged	29/05/2009	22.0	8.9	No	Filamentous green algae growing on trays
2	Emergent	29/05/2009	21.7	9.0	No	Grass, *Callitriche* and *Lemna* growing
3	Submerged	29/05/2009	22.0	8.9	No	Filamentous green algae growing on trays
4	Emergent	29/05/2009	21.7	9.0	No	Grass and other herbs growing
5	Submerged	29/05/2009	22.0	8.9	No	Filamentous green algae growing on trays
6	Emergent	29/05/2009	21.7	9.0	No	Grass and other herbs growing
1	Submerged	12/06/2009	29.4	7.7	No	Filamentous green algae growing on trays
2	Emergent	12/06/2009	31.0	7.8	No	*Callitriche*, grass and other herbs growing
3	Submerged	12/06/2009	29.4	7.7	No	Filamentous green algae growing on trays
4	Emergent	12/06/2009	31.0	7.8	No	Grass, *Juncus* and other herbs growing
5	Submerged	12/06/2009	29.4	7.7	No	Filamentous green algae growing on trays
6	Emergent	12/06/2009	31.0	7.8	No	Grass, *Juncus* and other herbs growing
1	Submerged	26/06/2009	21.1	7.7	No	Filamentous green algae growing on trays
2	Emergent	26/06/2009	22.4	7.8	No	*Callitriche*, grass and other herbs remaining
3	Submerged	26/06/2009	21.1	7.7	No	Filamentous green algae growing on trays
4	Emergent	26/06/2009	22.4	7.8	No	Grass, *Juncus* and other herbs remaining
5	Submerged	26/06/2009	21.1	7.7	No	Filamentous green algae growing on trays
6	Emergent	26/06/2009	22.4	7.8	No	Grass, *Juncus* and other herbs remaining

APPENDIX 3: PHOTOGRAPHS

Plate 1. Transect 1

Plate 2. Transect 2

Plate 3. Transect 3

Plate 4. Transect 4

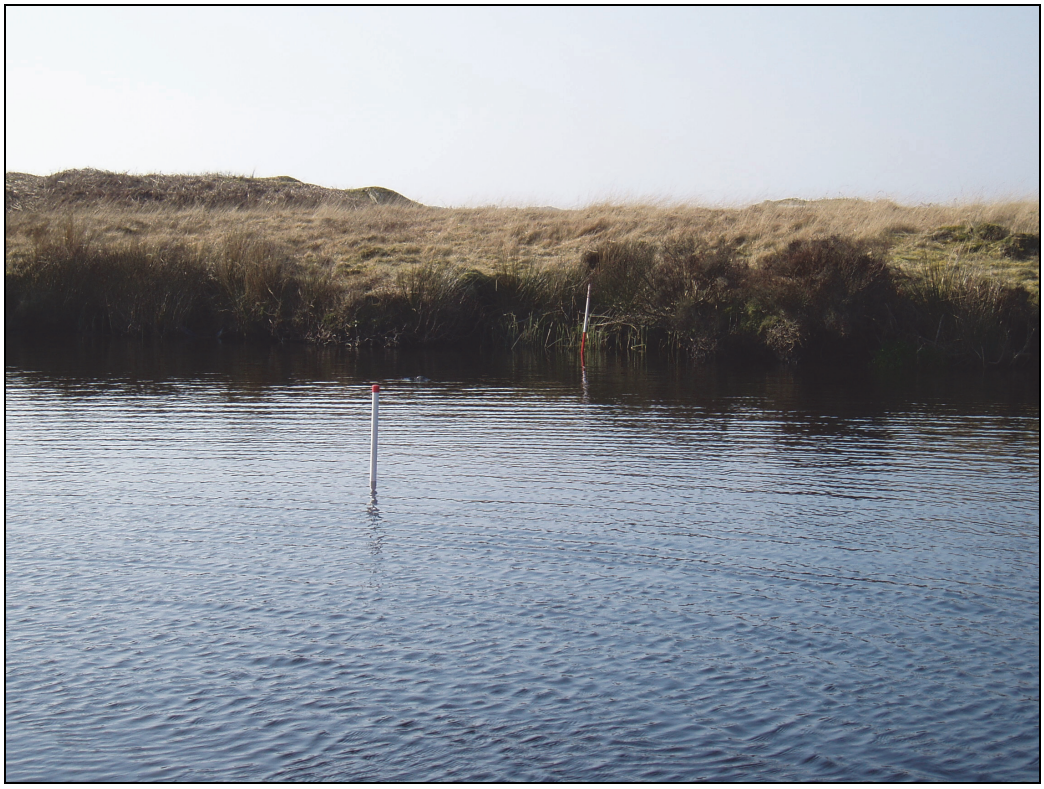

Plate 5. Transect 5

Plate 6. Transect 6

Plate 7. Weed control fabric in place

Plate 8. Removal of weed control fabric

Plate 9. C. helmsii growing between two sheets of weed control material

Plate 10. Weed control fabric re-applied to C. helmsii *growing between two sheets of weed control material*

Plate 11. Weed control fabric fraying due to contact with rocks

Plate 12. Weed control fabric damaged through deployment in Loch

Plate 13. C. helmsii *establishing on the shore above the level of the weed control fabric*

Plate 14. C. helmsii *growing in pockets of silt caught on top of weed control fabric*

Plate 15. Loch margins following removal of weed control fabric, March 2009

Plate 16. Substrate and dead plant material following removal of weed control fabric, March 2009

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